An Experiment on Releasing Water from Water Tanks by Xu Youzhen during the Ming Dynasty¹

Dai Nianzu 戴念祖, Zhang Xumin 张旭敏

(Institute for the History of Natural Sciences, CAS, Beijing 100190, China)

Abstract: In 1453, Xu Youzhen, a scholar-bureaucrat and hydrologist in Ming China, was dispatched to Shandong to find a way to harness the Yellow River. He proposed the opening up of multiple channels to diverge the flood waters. An experiment was conducted to compare the efficiency of releasing water using one large opening with the use of a number of small openings. This experiment proved that opening up multiple channels outperformed the construction of only one, thereby convincing the emperor and officials of the efficacy of this method. Xu's method for water control proved to be successful in averting a flood that occurred in 1456.

Keywords: experiment on releasing water from water tanks, flood management, hydromechanics, Xu Youzhen, Yellow River

As stated by Joseph Needham (1900–1995) and other historians of science, pre-modern China had abundant knowledge of physics and relevant technological experience but usually lacked experimental and theoretical knowledge. Nevertheless, there are records of physical experiments in Chinese sources that may deepen our understanding of the Chinese tradition of scientific knowledge and technology. An experiment on releasing water from a water tank, conducted by Xu Youzhen 徐有貞 (1407–1472) during the Ming dynasty (1368–1644), demonstrates that Chinese scholars also understood the importance of experiment and could design experiments to convince the authorities of the efficacy of certain engineering ventures.

Xu Youzhen was born in Wu County (present-day Suzhou, Jiangsu Province). It is said that he was "shrewd and capable, eyes brimming with radiating vigor" (Wang [n.d.]1986, 268), and attached great importance to so-called "practical subjects." In 1452,

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Xu was appointed assistant censor-in-chief² and dispatched to Shandong Province to find a way to harness the Yellow River, which frequently overflowed into almost every other dynasty. In today's town of Zhangqiu in Yangqu County, Xu "observed and analyzed the flow of water before he put forward three pieces of advice. The first was to construct a water gate, the second was to cut diversion channels, and the third was to dredge the Grand Canal" (Zhang 1739, 4561–4564).³ In order to decide which method would work best, Xu did an experiment on releasing water from a water tank. In his Wuli xiaozhi 物理小識 (Small encyclopedia of the principles of things), Fang Yizhi 方以智 (1611–1671) recorded that:

徐有貞張秋治水,或謂當濬一大溝,或謂多開支河,乃以一甕竅方寸者一,又以一甕竅之方分者十,並實水發竅,竅十者先竭。

When Xu Youzhen went to tame the river in Zhangqiu, some suggested that he should dredge one waterway, while others said that he should cut multiple diversion channels. Xu therefore prepared one water jar with an opening of one square $cun \ \ \ \ \ \$, and another jar that had ten openings, each measuring several square $fen \ \ \ \ \ \ \$ Both jars were filled with water. The openings of both jars were then unblocked. The jar that had ten openings emptied faster. (Fang [1643]1995)

The "water jar" (weng 甕) here is the equivalent of a water tank. While Fang's account did not make it explicit that the openings of the two jars were equal in size, according to Chinese tradition, speeds, sizes, or quantities of different objects are always compared under the precondition that the distance, the total space, or the total capacity are the same. It is stated in Part B of "Gaozi 告子" in Mencius 孟子 that:

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金重於羽者, 豈謂一鉤金與一輿羽之謂哉?
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When one says that gold is heavier than feathers, is one comparing a gold buckle with a cartload of feathers?⁵

According to Fang's account, since one of the two jars had one large opening measuring one square *cun*, the other one with ten small openings, each measuring several square *fen*, should therefore have had a total open area of one square *cun*. Only under such conditions could a comparison have been made. Fang's account conforms to the traditional Chinese way of expression.

It seems that, according to Fang, the most practical method of making the large

² In this paper, all official titles of ancient China are translated according to Hucker 2008.

³ This should be followed by "(and divert water from the Yellow River into the canal)." In this paper, if not specified, all direct quotations from Chinese sources are translated by the translator.

⁴ In the Chinese system of measurements, both *cun* and *fen* are units of length. 1 *cun* = 1/3 decimeter, 1 *fen* = 1/3 centimeter. Also, 1 square *cun* = 100/9 cm², 1 square *fen* = 1/9 cm².

⁵ The English translation is taken from Zhao et al. 2009.

opening of one square cun is to make it square-shaped. When it comes to making the ten small openings, however, it would not be easy to make each side of the square exactly $\sqrt{10}$ fen. It is more likely that these rectangular openings of 10 square fen would each have measured (2 $fen \times 5$ fen or 1 $fen \times 10$ fen). Suppose both jars are cylinders with an inside radius of 1 chi \mathbb{R} and that the height of water at the beginning of the experiment is 2 chi. When the discharge coefficient of the large opening and the small opening is 0.61 and 0.63 respectively, the results of calculation demonstrate that the jar with ten small openings would empty about six seconds faster than the jar with only one opening (Zhang 1998). On the other hand, however, Xu had no intention of determining the discharge coefficient, nor were his contemporary Chinese scholars aware of the physical concept of "discharge coefficient." The flow of water through openings and the flow of water in the open channels of rivers and canals actually belong to two different fields of hydromechanics. Xu had attempted to argue for the diversion of water from the main watercourse, a problem that belongs to the latter field, by conducting an experiment concerned with the former.

The description of this particular experiment by Xu Youzhen is also found in "Suzhou fuliqiao yuehe ji" 宿州符離橋月河記 (Records of the Yuehe River under Fuli Bridge in Suzhou) written by the poet Li Dongyang 李東陽 (1447–1516). The text was written to record the achievement of Vice Minister of the Ministry of Revenue Bai Ang 白昂 (1435–1503) in taming the river. Thirty-four years after Xu, Bai adopted the same method of cutting diversion channels and succeeded in harnessing the Yellow River. Li writes:

國朝凡四決,後為張秋都御史徐公有貞治之。有撓其議者曰: "不能塞河而顧開之邪?"使者至,徐出示二壺,一竅五竅者各一,注而瀉之,則五竅者先凋。使歸而議決。此白公之所親聞者也。

The Yellow River breached its banks four times in the present dynasty before it was harnessed by Mr. Xu, censor-in-chief of Zhangqiu. Someone who was opposed to his proposal said: "Does it make sense that we do not block the breach but dig open the waterway instead?" When an emissary of the court arrived, Xu presented two teapots, one of which had one opening and the other had five. Xu filled the pots and then let the water flow out of them. The pot with five openings emptied faster. The emissary returned and the decision was made. This was what Mr. Bai himself had witnessed. (Chen et al. 1962, 426)

"Mr. Xu" refers here to Xu Youzhen and "Mr. Bai" is Bai Ang. Xu's experiment to release water from a jar was conducted in 1453 and at that time Bai was already 18

⁶ As has been analyzed above, the total area of these ten small openings should be equal to 1 square *cun* and each of them is then 10 square *fen*.

⁷ Chi is another unit of length in the Chinese system of measurements. 1 chi = 1/3 meter.

years old. This account of Bai witnessing Xu's experiment and following his example in his later practice of harnessing the river appeared much earlier than Fang's report. In his report of Xu's experiment, Li did not make it clear either that the total area of openings in the two pots were equal. According to Chinese cultural tradition, it is obvious that the area of one large opening should equal the total area of the five small openings. Meanwhile, Li and Fang disagreed on the number of openings of the water container—Li said it had five openings while Fang reported that it had ten. This indicates that Xu probably repeated his experiment several times with water containers that had different numbers of openings. Li and Fang chose to write about different situations.

In the historical materials of the Ming and Qing dynasties, there are some other books that not only recorded Xu's experiment but also added that after Xu had convinced the senior court officials of the success of his experiment, the Jingtai emperor also observed it and approved Xu's proposal to open up diversion channels to control the flood (Gu [1658]1977, 502–504; Xia [n.d.]1959, 1078). In 1456, one year after his task had been accomplished, the section of the Yellow River flowing through Shandong Province flooded and a large number of dams were breached; only those constructed by Xu remained intact (Zhang et al. [1739]1974, 4561–4564). Xu's success in harnessing the Yellow River was acclaimed by officials and also by the residents living near the river bend in Zhangqiu (Xie [n.d.]1986, 611). Xu received imperial rewards for his contribution and was further promoted.

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